

Gloss Archiving with Normal Vectors

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Abstract

This paper proposes a method of gloss archiving using normal vectors. When archiving the gloss phenomenon of a material, it is important to record not only the reflected light intensity but also the gloss unevenness. This is because the gloss unevenness greatly affects the texture of the material. However, it has been difficult to quantitatively record gloss unevenness because they are dependent on the viewing direction and lighting. Gloss unevenness on mirror surfaces are mainly caused by irregularities in the normal direction. Therefore, we came up with a solution to archive the gloss unevenness phenomenon by recording the distribution of surface normal vectors. We are currently developing a apparatus to measure the distribution of surface normal vectors. Using this surface normal data, it will be also possible to reproduce gloss unevenness images using Computer Graphics technology.

1. Introduction

Gloss is an important phenomenon that gives a sense of the texture of a material. We humans read further information about the texture of the material from the gloss unevenness. Gloss unevenness is physically the specular reflection phenomenon, as shown in Figure 1. From a macroscopic viewpoint, even though the gloss is constant, the appearance of gloss unevenness occurs with the direction of the normal vector. The main cause of gloss unevenness is the mesoscopic undulations of the object surface. The gloss unevenness is caused by differences in reflection on the object surface.

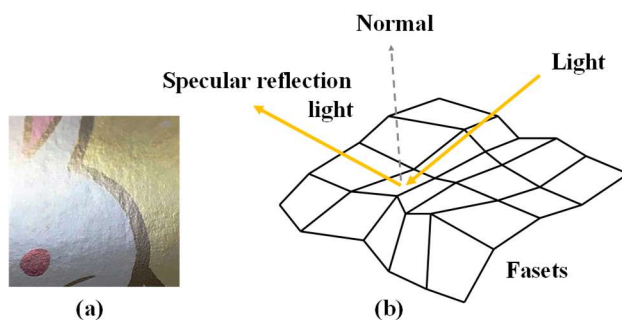


Figure 1. (a) Enlarged photograph of an area where gloss unevenness is observed (30 x 30 mm). (b) Schematic diagram of the gloss phenomena. The observed specular reflection direction changes as the direction of normal changes.

The texture, the material, may be estimate from the gloss unevenness, as shown in Figure 2. We humans estimate the

texture of an object by moving the object, the direction of incident light, and the viewing position.

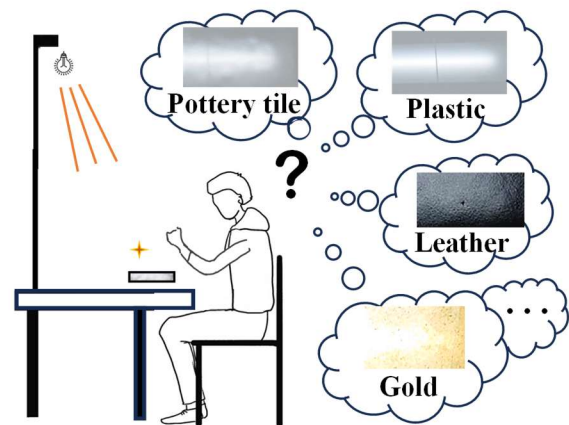


Figure 2. Schematic diagram of object observation. With the gloss unevenness, the texture can be recognized.

Since gloss unevenness is a visible phenomenon, it is easy to record it in photos. Gloss unevenness can be captured with a camera. However, this is just one way in which the gloss unevenness phenomenon can appear. The appearance differs depending on the viewing angle, as shown in Figure 3. Measurement and analysis of gloss unevenness under certain conditions have been reported [1,2]. Methods for measuring gloss unevenness at limited different angles have been proposed [3,4]. However, a method to physically record the entire gloss unevenness phenomenon has been desired.

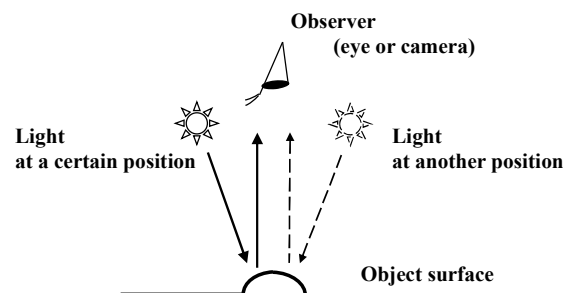


Figure 3. Schematic diagram of the observation of gloss unevenness. Gloss unevenness varies with light and eye angle.

The reflectance of an object surface at different angles can be measured. The reflectance at a different angle is named gonio-reflectance and can be measured with a goniophotometer [5].

The universal way to describe physical reflectance properties is via the bidirectional reflectance distribution function (BRDF) [6,7,8]. However, its measurement area range is too large, e.g., 5.0 mm. Gloss unevenness is a phenomenon in much smaller areas.

This paper proposes a method of gloss archiving using normal vectors. The normal vectors are able to measure by our developing apparatus. The optical system illuminates with light from a different direction, angles and capture image of a gloss unevenness in each condition. And we demonstrate that the proposed method can estimate the surface normal vectors. We discuss the merits and demerits of the proposed method for archiving gloss phenomenon.

2. Approach

Our proposal is to use the surface normal vectors for archiving the gloss unevenness. We have come up with this proposal based on the hypothesis that gloss unevenness is caused by unevenness in the surface, i.e., mesoscopic surface irregularities. A problem is to measure the normal vector at every facet on the surface.

The facet normal is estimated as follows. In reflection theory, the specular reflection vector is determined from the incident light vector and the normal vector of the facet (see Figure 1). If we change the direction of the incident light vector and measure the intensity of reflection, when it becomes largest it will be the specular reflection relationship. The normal vector $\mathbf{n}$ will be the half vector $\mathbf{h}$ of this incident light vector $\mathbf{l}$ and the observed vector $\mathbf{v}$ as follows:

$$\mathbf{n} = \mathbf{h} = \frac{\mathbf{l} + \mathbf{v}}{|\mathbf{l} + \mathbf{v}|} \quad (1)$$

However, the facet areas are small and it is difficult to measure the facets continuously across the entire sample surface. We tried the following approach to solve this problem.

First, light is incident on the entire sample surface from the same direction, and the angle of incident light to each facet is determined. Next, this reflected light is captured by a digital image sensor so that it is in one direction for all facets. This also determines the observation vector. This procedure is repeated by changing the angle of incident light, and the normal is estimated from the angle of incident light when the amount of reflected light from the facet is maximized. We use a new apparatus in this paper. The processing procedure for estimating the normal vector is shown in Figure 4. The incident light angle is successively changed, the reflected image is measured. Then the incident angle at which the value of each pixel is maximized is determined.

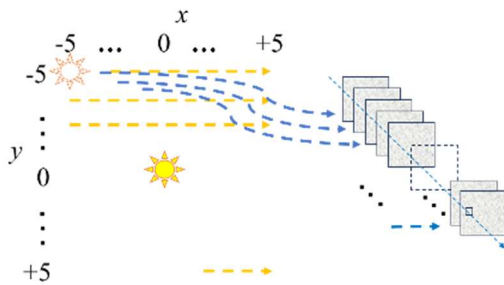


Figure 4. Schematic diagram of the processing procedure for estimating the normal vector.

We focused on two techniques for developing the measurement apparatus. That is the variable directional lighting optics using the collimator optics system and the one directional light imaging method by the telecentric optics system.

A schematic diagram of the collimator optics system is shown in Figure 5. In collimator optics, there is a focal point on one side of the lens and parallel light on the other side. Parallel light can be emitted by the illumination system if the light source is set at the focal point.

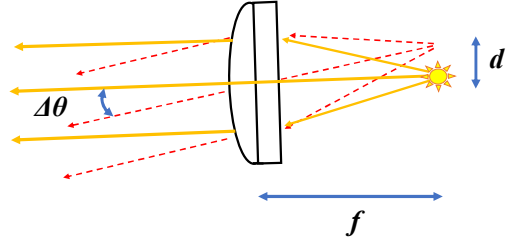


Figure 5. Schematic diagram of collimator optical system. The distance from the center, d , can be calculated from focal length, f , and light angle, $\Delta\theta$.

The distance from the center, d , is calculated from the light angle, $\Delta\theta$, and the focal length, f , as follows:

$$d = f \cdot \tan(\Delta\theta) \quad (2)$$

Usually, the light source position is at the focal point and in the center. In the newly developed apparatus, as shown in Figure 3, the light sources can be variable positioned to project collimated light at the desired angle. The angle of incident light is the same everywhere on the sample.

To make the measurement angle also the same everywhere, telecentric optics are applied. Telecentric optics system is an optical system that allows only light parallel to the optical axis to pass through in Figure 6.

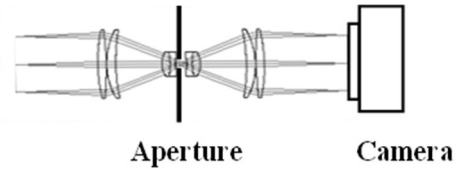


Figure 6. Schematic diagram of the telecentric optics system.

3. Experiment and Result

We developed a measurement apparatus in Figure 7, 8. The collimated light emitted from the collimator lens is reflected by a half mirror before entering the sample. The angle of the CMOS camera (DFK 33UX249, Imaging Source) was fixed at 0° to the sample surface. The effective measurement area is approximately 20×20 mm, 1024×1024 pixels. The sample material was set on the sample bed, and the images were acquired in a darkroom. The apparatus is developed by Chuo Precision Industrial Co., Ltd..

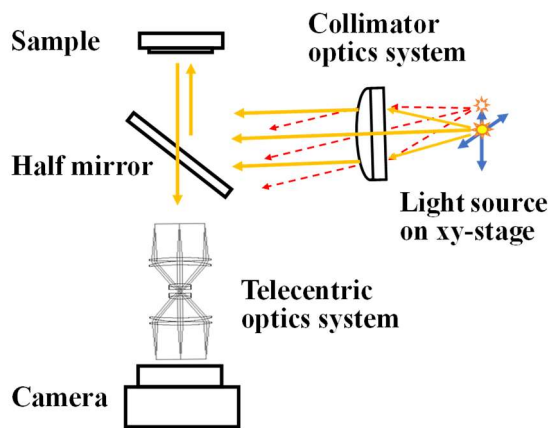


Figure 7. Schematic diagram of the measurement apparatus with the variable directional lighting system.

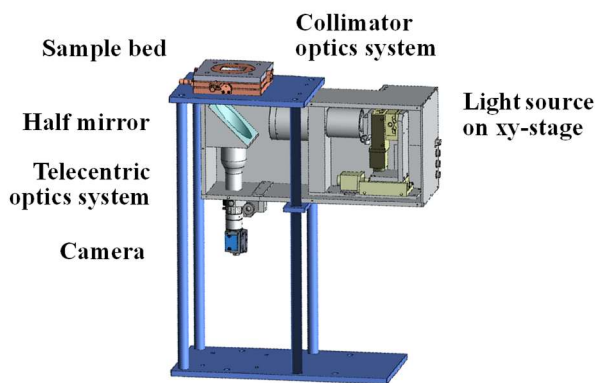


Figure 8. Configuration diagram of the measurement apparatus.

The gloss unevenness images were measured. There were six materials. These samples were flat shape. The samples used were mirror, aluminum sheet, inkjet paper, pottery tile, leather, gold leaf and v-cut calibration sample. The v-cut is to verify the measurement principle, a material with a known surface profile. It has a double-striped surface with a pitch of 1.0 mm (width of 0.5 mm) and angles of 1.0° and -1.0° . The surface is mirror-like.

The measurement results of this apparatus are shown in Figure 9. The photo on the left is a photograph of the sample. The two images in the middle and right are measurement images illuminated from different directions. The measurement image is of an area of 20mm x 20mm. It can be seen that the gloss unevenness of the material is being measured. As pointed out in the introduction, it can also be seen that the gloss unevenness appears different depending on the direction of the illumination light. In this experiment, lighting was used from 121 directions (11×11) and 121 images were taken. Two representative images have been appropriately selected and shown in the Figure 9.



Figure 9. Photograph of the samples (left) and typical two measurement images illuminated from different directions. (middle and right).

The normal vectors were estimated from these images. The one of result is shown in Figure 10. The image on the left is measurement image illuminated from a direction. The image on the right is the estimated normal vectors. The normal vector of each facet is a three-dimensional numerical value. Here, the deviation from the zenith, which is 0 degrees, is shown with an arrow. This measuring apparatus can estimate the normal of facets of 20 x 20 micrometers, i.e. 50 points/1 mm, so the amount of information is large even for a small area. A technology is needed to consolidate gloss unevenness into a representative evaluation value that can adequately represent the unevenness. Reproducing gloss unevenness using computer graphics is one important solution.

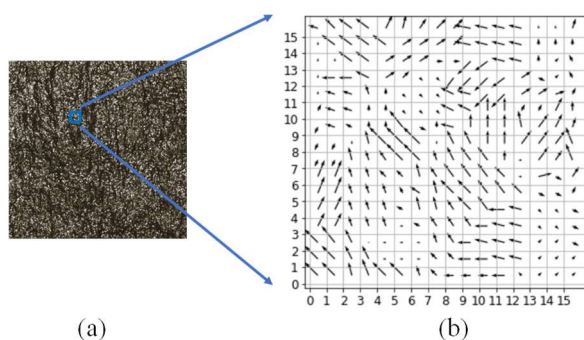


Figure 10. (a) The measured gloss unevenness images. (b) The estimated normal in part of surface.

4. Discussion

We discuss the advantages, disadvantages, and challenges of the proposed method.

4.1 A Photograph or Normal Vectors:

For archiving gloss unevenness, which is better a photograph or normal vectors? As already discussed in the introduction, photographs, which look different depending on the viewing angle, are not suitable for quantitative analysis of gloss unevenness. However, it should be noted that in order to recognize texture, it is easier to understand by looking at a photograph. Figure 9 shows a photograph of the material and two gloss unevenness measurement images. Humans can roughly understand the texture and gloss unevenness of a material by looking at a photograph. Although the measurement image is recorded with greater precision, they are difficult to understand gloss unevenness intuitively.

Note that the non-glossy areas in the measurement images are completely black. In general, the amount of specular reflected light is much stronger than the diffuse reflected light that we see, so within the dynamic range of a camera that can measure gloss, the amount of light outside of this is too small to measure, i.e., black. This dynamic range issue also poses a challenge when recreating it in Computer Graphics.

4.2 Reproduction using Computer Graphics:

Computer graphics can be used to reproduce gloss unevenness from normal vectors, but we have found that there are still many challenges. The only image that can be reproduced from normal vectors is gloss. Shape, color, etc. are necessary to reproduce the original material as an image. Furthermore, even if gloss is calculated physically, there are no devices that can reproduce it. Changes in appearance due to high dynamic range processing must be considered in advance. Because computer graphics can create arbitrary images by manipulating parameters, there is no guarantee that the original archived material will look the same again. Figure 11 shows the represent images by computer graphics using normal vector in example.

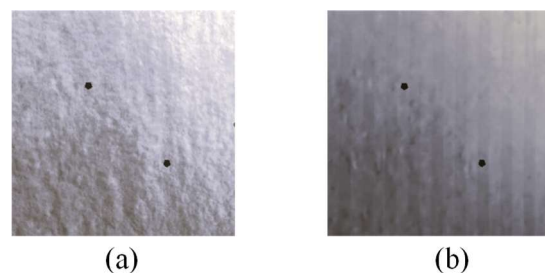


Figure 11. The represent images by computer graphics using normal vector. (a) Inkjet paper sample. (b) V-cut calibration sample.

4.3 Psychological evaluation of texture using normal vectors:

Our future work is to analyze the relationship between psychological evaluation of texture and gloss unevenness. To do this, we need technology to simulate gloss unevenness. We will be working on technology to simulate gloss unevenness using computer graphics.

4. Conclusion

We have proposed to archive gloss phenomena using normal vectors. We have developed the apparatus that images gloss unevenness and estimates the normal vectors of the surface. We have shown that this method enables physical and quantitative archiving of gloss phenomena. Using this normal vector, it is possible to reproduce gloss unevenness by computer graphics. Future work is to analyze the relationship between psychological evaluation of texture and gloss unevenness. For this purpose, we will also work on a technique to reproduce gloss unevenness by computer graphics.

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